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SOME CHARACTERISTICS OF GROUNDED FLOEBERGS NEAR PRUDHOE BAY, AL--ETC(U)
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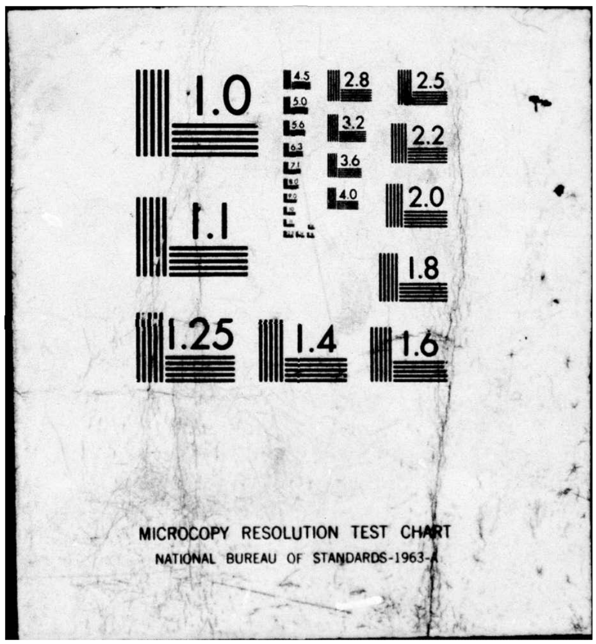
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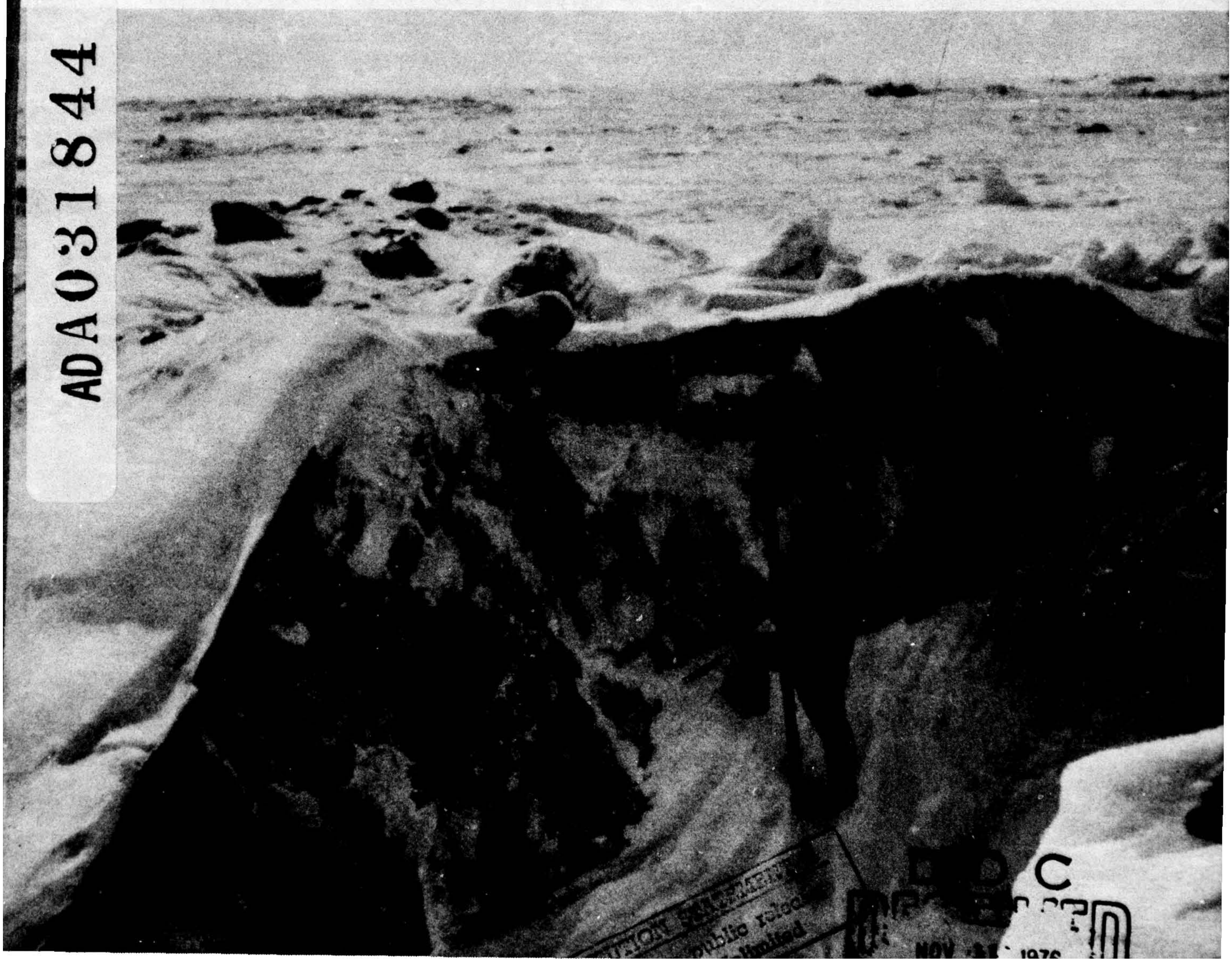

For conversion of SI metric units to U.S./British customary units of measurement consult ASTM Standard E380, Metric Practice Guide, *published by the American Society for Testing and Materials, 1916 Race St., Philadelphia, Pa. 19103.*

Cover: *Exposed section through center of floeberg showing structural arrangement of ice blocks. (Photograph by Austin Kovacs.)*

CRREL Report 76-34

Some characteristics of grounded floebergs near Prudhoe Bay, Alaska

Austin Kovacs and Anthony J. Gow

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Some physical characteristics of two grounded floebergs near Prudhoe Bay, Alaska, are described. Cross-sectional profiles of the sails and keels of both floebergs were obtained. Additional studies included investigations of the internal structure of the floebergs, surveys of the sea floor for evidence of scoring induced during grounding of the floebergs, and a brief examination of the organic and sedimentary debris found entrained within the floebergs.

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PREFACE

This report was prepared by Austin Kovacs, Research Civil Engineer, of the Foundations and Materials Research Branch, Experimental Engineering Division, and by Dr. Anthony J. Gow, Geologist, of the Snow and Ice Branch, Research Division, U.S. Army Cold Regions Research and Engineering Laboratory. It is funded by the U.S. Department of Commerce National Oceanic and Atmospheric Administration under Purchase Order 01-5-022-1651.

Technical reviewers of the manuscript were Dr. W.F. Weeks and S. Ackley of CRREL.

(fragments of multi-year pressure ridges)

SUMMARY

Some physical characteristics of two grounded floebergs near Prudhoe Bay, Alaska, are described. Cross-sectional profiles of the sails and keels of both floebergs were obtained. A sail to keel ratio of 1 to 3.38 obtained with one floeberg was found to be in good agreement with previous investigations. A survey of the sea floor for evidence of scoring induced during grounding yielded a maximum depth of gouging of 1.1m. Additional studies included investigations of the internal structure of the floebergs, and a brief examination of the organic and sedimentary debris found entrained within the floebergs.

The grounding of ice on the continental shelves of the Arctic is of considerable interest to those concerned with the development and impact of development of these continental shelves. The field study reported here provides information useful in assessing the nature and characteristics of interactions between floebergs and the sea bed on which they are grounded.

SOME CHARACTERISTICS OF GROUNDED FLOEBERGS NEAR PRUDHOE BAY, ALASKA

Austin Kovacs and Anthony J. Gow

INTRODUCTION

During the winter of 1974-75 a large number of floebergs (fragments of multi-year pressure ridges) were found incorporated in the fast ice northwest of Prudhoe Bay, Alaska, between Bodfish and Cross islands. Many of the floebergs had been driven up onto the sea floor and had become stranded, as indicated by their high freeboard. The grounding of ice on the continental shelves of the Arctic is of considerable interest, not only to the oil industry which is beginning to develop the oil and gas reserves located offshore, but also to environmental groups concerned with the safety of offshore producing platforms and bottom-founded structures. Much of this interest concerns the forces which develop when large, deep-drafted ice becomes grounded and is then pushed by the pack across the sea floor. During this process the sea bed may become gouged, scored or otherwise extensively modified by the plowing action of the ice. Thus, for both economic and environmental reasons, sea floor production systems must be designed to resist these forces or be buried below the deepest contemporary ice scoring.

In order to gather information on the geometry of the floebergs and their effect upon the sea bed during grounding, a short field study was made in April 1975 of stranded floebergs near Prudhoe Bay. The observations included the determination of the surface relief and snow thickness of two floebergs with standard surveying techniques, and the profiling of the floeberg keel by using a sonar technique developed by Kovacs (1970). In addition, the internal structure, and void and impurity content in the floebergs were determined by visual examination of fracture faces on the floeberg sail and of the portion of the keel uplifted upon grounding.

STUDY AREA

The area of the study was located approximately 12 km north of Long Island (Fig. 1). Two aerial views of the area are shown in Figure 2. The highly deformed zone of sea ice shown in Figure 2a occurs at the boundary between the fast ice and the moving pack. This formation is composed of shear ridges which are the result of the shearing forces developed at the boundary. This particular formation, often much longer and wider, is known to re-form each year at this location. The first report of the occurrence of the shear ridge fields in these waters was, perhaps, that of Stockton (1890) who observed one formation 16 km long that was grounded in 24 m of water.

A surface view of the area of grounded floebergs near the study site is shown in Figure 3. The lower photograph (Fig. 3a) shows that the fast ice surface was highly irregular, the result of the incorporation of ice fragments into the ice sheet during freeze-up. The surface was found to be covered with a layer of snow that varied in thickness from 10 to 40 cm, depending on the extent of the local ice relief. Both floebergs were pushed upward and tilted toward the side that first contacted the sea floor during grounding. The heights of the floebergs in Figure 3b and 3c were 7 and 9.5 m, respectively.

RESULTS AND DISCUSSION

Two floebergs, A and B, were investigated in detail. An aerial view of floeberg A is shown in Figure 4. The north face of the floeberg was found to have an accumulation of broken first year ice piled upon it. This accumulation of ice indicates that the floeberg was driven aground during a storm which pushed ice from the north toward the coast. Upon grounding floeberg

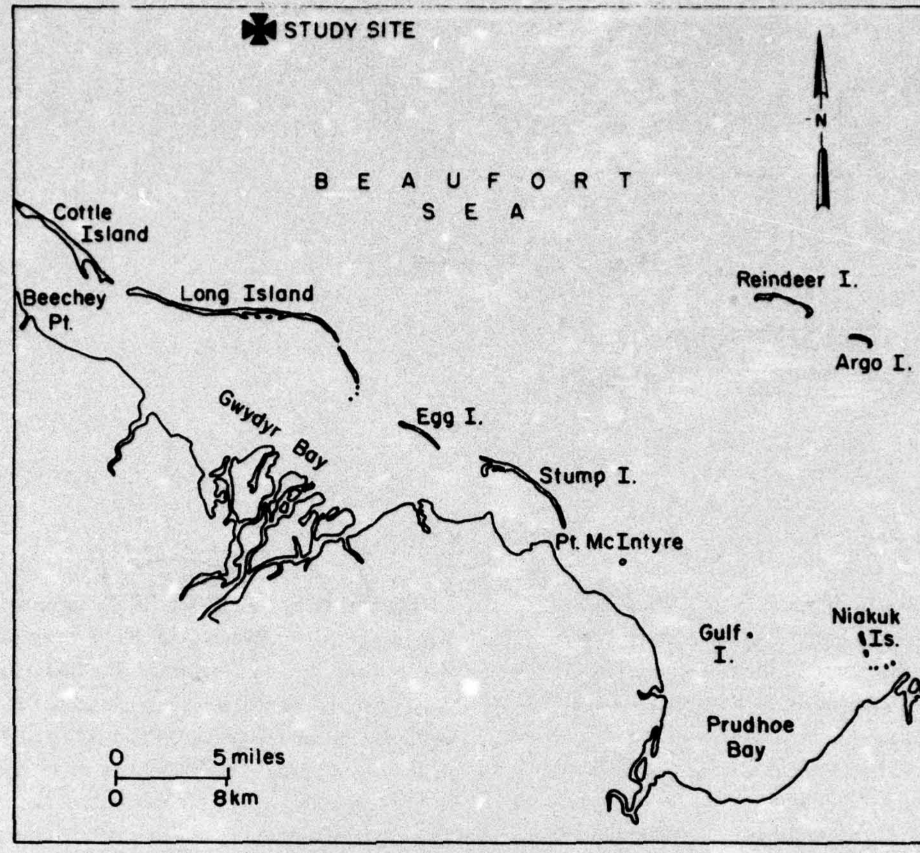


Figure 1. Map of Prudhoe Bay area showing location of floeberg study site.

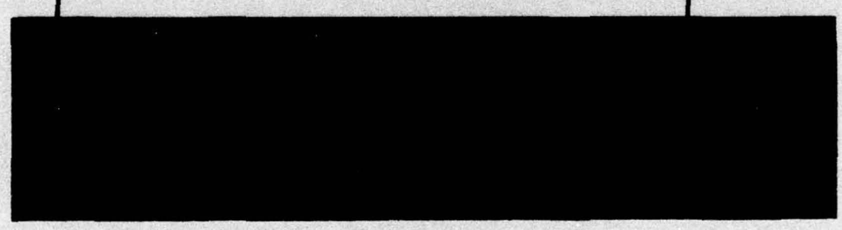
a. Deformed zone marking boundary between fast ice and the moving pack.

Figure 2. Aerial photographs of ice features in the immediate area of the study site.

b. Grounded floebergs.

Figure 2 (cont'd).

Enlarged views of floebergs.



a. General surface view of floebergs and surrounding ice.

Figure 3. Grounded floebergs at study site.

A became immobile. The pressure on the first year ice to the north of the formation continued to force the ice sheet southward. Unable to resist the stresses developed, the ice sheet failed against the floeberg, causing the broken ice to accumulate in a pile on its north side and leaving a wake of ice fragments trailing to the south.

A vertical view of floeberg A is shown in Figure 5. This view shows that the floeberg surface is substantially free of voids; that is, all space between the original ice blocks is now thoroughly cemented with frozen meltwater or rainwater. The fracture faces on the east and west sides of the floeberg also lacked voids. Thus, for all intents and purposes, this fragment of a

Figure 4. Aerial view of floeberg A, marked by arrow.

Figure 5. Vertical view of floeberg A. The line of drill holes marked A-L measures approximately 44 m; arrows indicate the position and direction of the cross-sectional profile (in Fig. 8).

multi-year pressure ridge now consisted entirely of solid ice.

A view of the floeberg from the east is shown in Figure 6; note the roughness of the surrounding ice surface and the variable thickness of snow cover. Figure 7, a closer view of the east side of the floeberg, shows a distinctive ice shelf or ledge at about the same level as the man's head. This ledge encircled the floeberg completely and marked the position of the waterline when the ice formation was free-floating. The ledge was elevated approximately 1.85 m above the surrounding ice surface, indicating that the floeberg had been driven upward onto the sea floor by this amount during grounding.

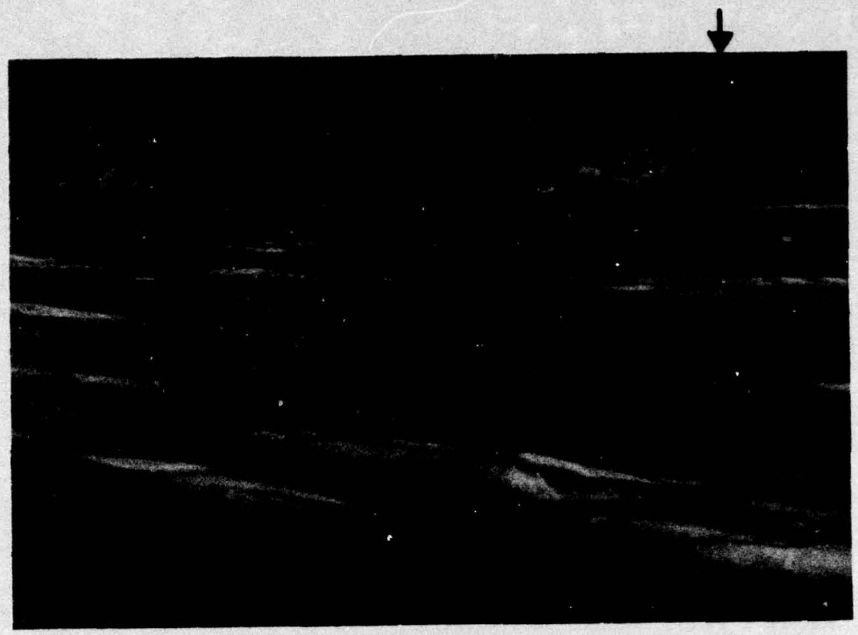


Figure 6. View of floeberg A (marked with an arrow) and surrounding surface features.

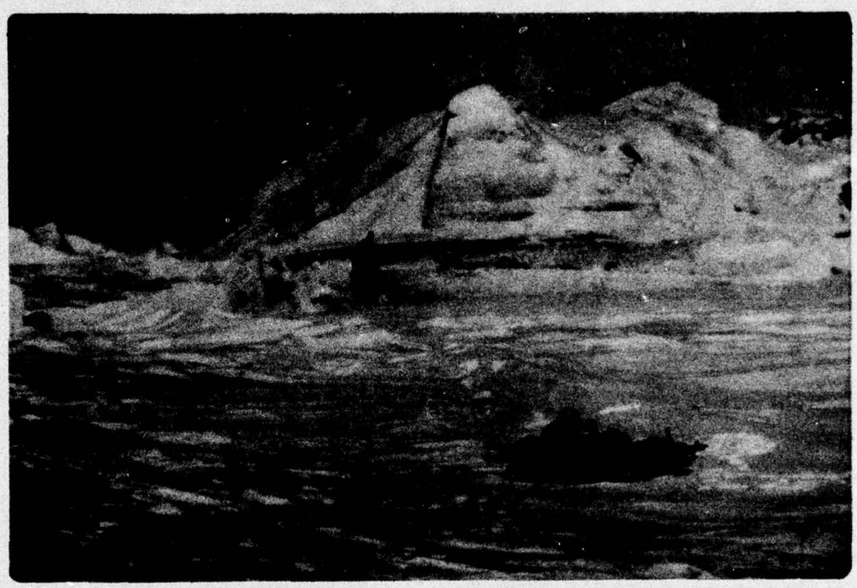


Figure 7. Close-up of grounded floeberg A. Note original wave-cut ledge now elevated to level of man's head.

The cross section of floeberg A is presented in Figure 8a. No voids were encountered at the site of the exploratory hole, indicating that this part of floeberg A was composed of thoroughly cemented blocks of ice. The maximum sail height of floeberg A was 6.06 m; the keel depth measurement was approximately 12.4 m. If we now adjust these dimensions for the uplift of 1.85 m associated with grounding, then the sail height reduces to 4.21 m and the keel depth increases to 14.25 m. This yields a sail height to keel depth ratio of 1 to 3.38, which is in good agreement with the 1 to 3.3 sail height to keel depth ratio found by Kovacs et al. (1973) and the 1 to 3.13 ratio found by Kovacs (1976).

To determine if the ice keel had scored the sea floor during grounding, a series of holes (marked A-L in

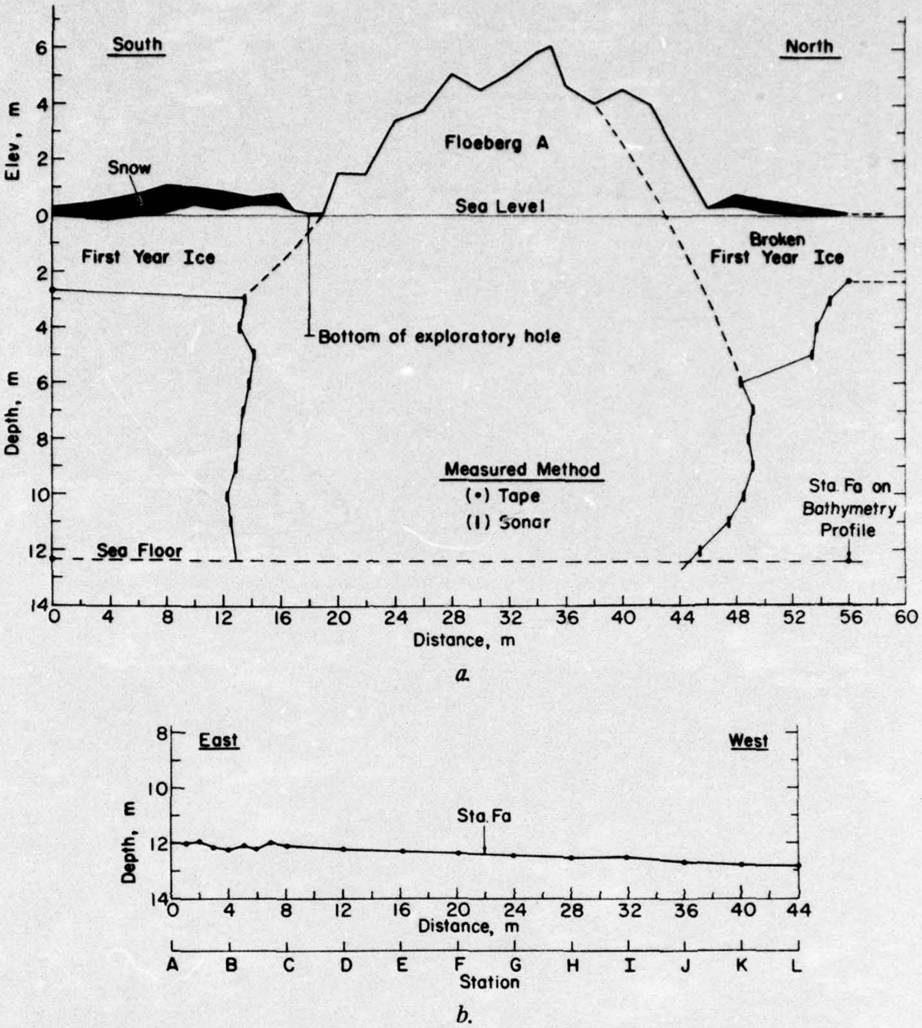


Figure 8. (a) Cross-section of floeberg A and (b) profile of sea floor measured directly behind floeberg A.

Fig. 5) were drilled through the ice cover along a line parallel to the north side of the floeberg. The depth to the sea floor was then measured by lowering a weighted tape through the holes. Results of these measurements, presented graphically in Figure 8b, reveal some microrelief between stations A and C, where depth measurements were made every meter, but no major depression was observed which would indicate that the keel had significantly scored the sea floor. Soundings made along the east and west side of the floeberg also failed to reveal any definite trace of scoring of the sea bed. This lack of scoring behind floeberg A might be attributed to a flat-bottomed keel that slid, rather than "plowed," through the sea floor, which at this location was composed mainly of coarse sand.

An aerial view of floeberg B is shown in Figure 9. The floeberg was roughly triangular in shape, and as with floeberg A, a large accumulation of fragmented first-year ice was piled along its north side. Trailing to the south was a wake of broken ice. As with floeberg A, these observations imply that floeberg B had gone aground during a storm which had driven the ice cover southward toward the coast. This grounding was accompanied by uplift of the floeberg onto its present position. Eventually the floeberg became so firmly grounded that the thin first-year ice failed and began to pile up on its northern face. In this particular

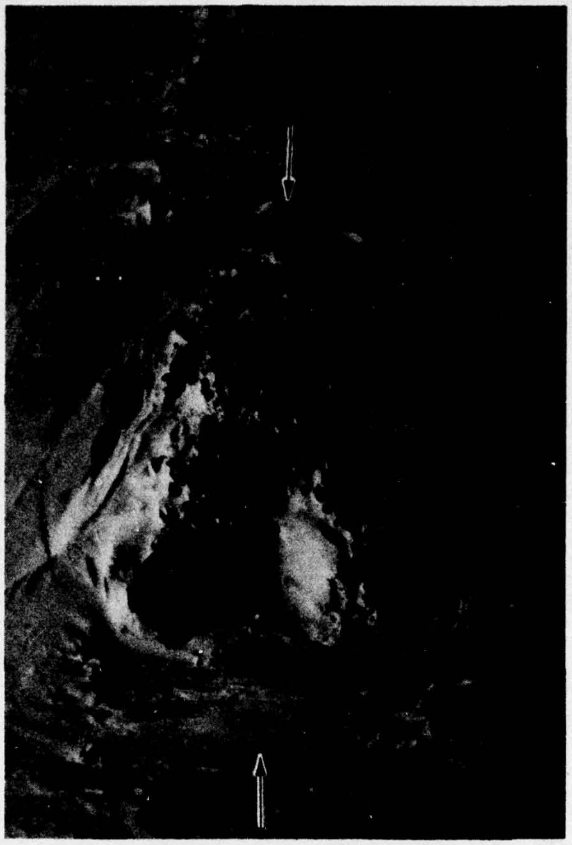


Figure 9. Aerial view of floeberg B. The line of drill holes marked A-M measures approximately 52 m; arrows indicate the position and direction of the cross-sectional profile (Fig. 11).

Figure 10. Close-up of grounded floeberg B. Floeberg is tilted down towards man in center of photograph.

instance, the weight of additional ice caused the floeberg to tip to one side. This tilting of floeberg B prevented us from making any accurate assessment of the total uplift associated with grounding. The raised keel and inclined wave-cut ledge on the south side of the floeberg are clearly illustrated in Figure 10.

A cross section of floeberg B is given in Figure 11a. The highest elevation on the surface profile was 6.65 m, and the keel is shown to be grounded in approximately 12.5 m of water. The extent to which first-year ice has piled on the north side of the floeberg is also indicated.

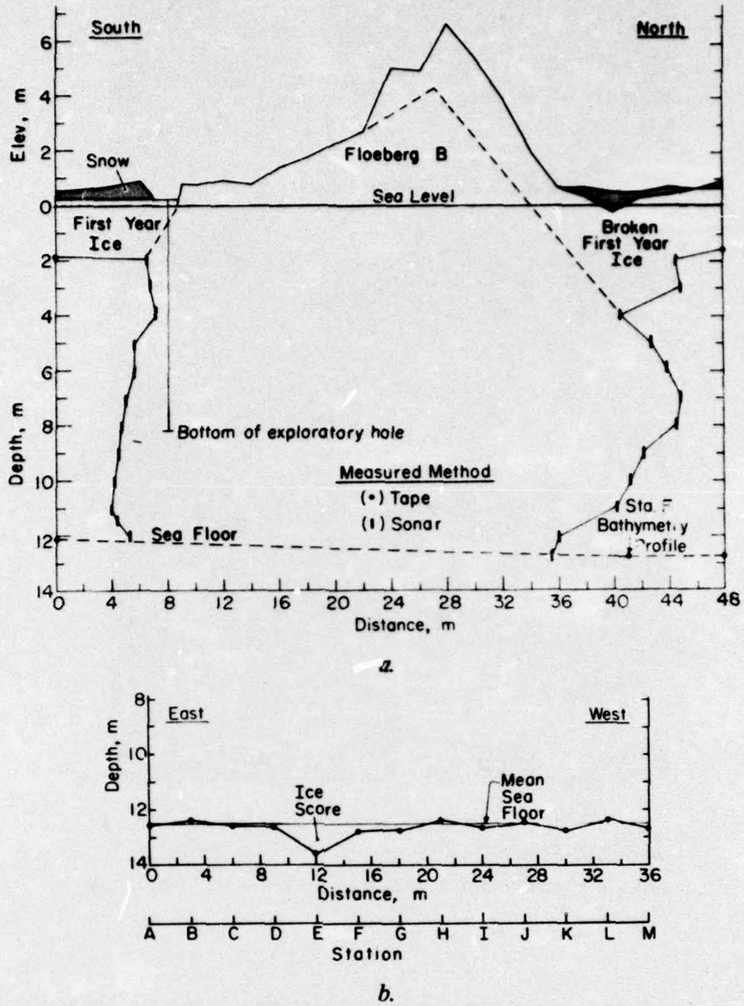


Figure 11. (a) Cross section of floeberg B, and (b) profile of sea floor measured directly behind floeberg.

The profile of the sea floor immediately behind the floeberg is shown in Figure 11b. The sea floor has a deep depression near the center of the north face of the floeberg at station E. On each side of this depression the sea bed has an undulating relief with a mean elevation of approximately 12.5 m. The depression is believed to have been created by the keel of the floeberg as it plowed into the sea floor during grounding. The maximum depth of the score below the mean sea floor depth is 1.1 m. It is approximately 15 m wide and has an average depth of 32 cm.

Large numbers of ice keels, coming aground on the arctic shelf, have caused widespread scoring of the sea floor. The effect of this scoring on biological activity of the sea floor is significant, for as Geikie (1882), Wright and Priestley (1922), Rex (1955), Kovacs and Mellor (1971), Kovacs (1972), Reimnitz and Barnes (1974), Barnes and Reimnitz (1974) and others have reported, contemporary ice scoring causes mixing of sea bed deposits, destroying stratification and allowing for oxygenation of the sediments. Such interaction of ice with the sea floor not only disrupts bottom conditions sufficiently to hinder the growth of plants, it also inhibits occupation of the sea bed by many marine species which might otherwise inhabit the area.

Visual examination of some 50 floebergs in the general area of floebergs A and B showed that all

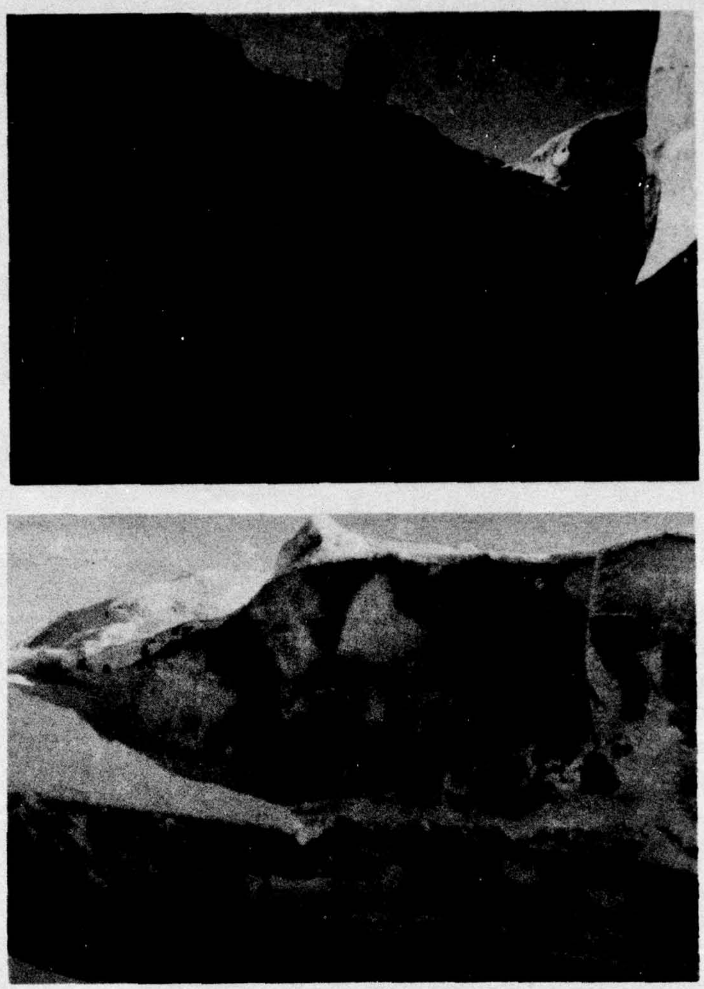


Figure 12. Exposed portions of two floebergs showing structural arrangement of ice blocks. Ice at each location contains abundant algae remains and some sedimentary material (dark patches). Note also the distinctive layer of debris (arrows) on exposed, ablated surfaces of floebergs.

Figure 13. Deposit of coarse sand and a fragment of tundra mat observed at foot of floeberg A.

were composed of tabular blocks and assorted fragments of ice, ranging in size from a few centimeters to several meters across, and firmly cemented together with little or no trace of voids. Internal structure was best revealed in the exposed faces of floebergs that had split apart, and some typical examples of such structure are presented in Figure 12 and the photograph on the cover.

All floebergs contained variable quantities of debris enclosed within and between the blocks of ice. Most of this debris was organic, composed principally of brown algae that had obviously been trapped in the ice during freezing. Sedimentary material was identified as of mainly silt-clay composition, though sand and gravel-sized debris (Fig. 13) were occasionally observed. The finer sedimentary particles are probably of eolian origin, but the exact source and manner of entrapment of the coarser particles, e.g. pebbly sand, has not been firmly established.

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